REMOTE WIRELESS UNIT HAVING REDUCED POWER OPERATING MODE FOR A DISCRETE MULTITONE SPREAD SPECTRUM COMMUNICATIONS SYSTEM

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This patent application is a Continuation-In-Part of the copending US patent application by David Gibbons, et al. entitled "REMOTE WIRELESS UNIT HAVING REDUCED POWER OPERATING MODE", serial number _____, filed February 6, 1997, and assigned to AT&T Wireless Services Inc. (Docket: Gibbons 1-1, 2445-4340US1)

CROSS-REFERENCES TO RELATED APPLICATIONS:

The invention disclosed herein is related to the co-pending U.S. patent application by Siavash Alamouti, Doug Stolarz, and Joel Becker, entitled " VERTICAL ADAPTIVE ANTENNA ARRAY FOR A DISCRETE MULTITONE SPREAD SPECTRUM COMMUNICATIONS SYSTEM", serial number _____, filed on the same day as the instant patent application, assigned to AT&T Wireless Services Inc., and incorporated herein by reference.

The invention disclosed herein is related to the copending US patent application by Alamouti, et al., entitled "Method for Frequency Division Duplex Communications", serial number_____, filed February 6, 1997, assigned to AT&T Wireless Services, and incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to improvements to communications systems.

More particularly, the present invention relates to wireless discrete multitone spread spectrum

5 communications systems.

2. Description of the Related Art

Wireless communications systems, such as cellular and personal

communications systems, operate over limited spectral bandwidths and must make highly

10 efficient use of the scarce bandwidth resource for providing good service to a large population

of users. A Code Division Multiple Access (CDMA) protocol has been used by wireless

communications systems for efficiently making use of limited bandwidths and uses a unique

code for distinguishing each user's data signal from data signals of other users. Knowledge of

the unique code with which any specific information is transmitted permits separation and

15 reconstruction of each user's message at the receiving end of the communication channel.

Adaptive beamforming technology has become a promising technology for

wireless service providers for offering large coverage, high capacity, and high quality service.

Based on this technology, a wireless communication system can improve its coverage

capability, system capacity, and performance significantly. A personal wireless access

20 network (PWAN) system, described in the cross-referenced Alamouti, Stolarz, et al. patent

applications, uses adaptive beamforming combined with a form of the CDMA protocol known

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as discrete multitone spread spectrum (DMT-SS) for providing efficient communications

between a base station and a plurality of remote units (RUs).

The remote units are powered primarily from AC power sources and include a

battery for providing battery backup power when AC power fails. To conserve battery power,

5   an RU has a sleep mode of operation with periodic power-up modes for checking whether any

calls are attempting to be connected to the RU. When an RU is in a sleep mode, it expedient

that the system operate in such a way so that appropriate actions are taken for completing a call

to a sleep mode RU.

One approach for ensuring that calls are completed to a remote unit operating in

10   a sleep mode is to maintain a database at a central location that stores the current operating

mode of each remote in the system. When a remote unit enters a sleep mode of operation, the

remote unit reports the change of operational status to the database. Similarly, the remote unit

reports a change of status back to a standby operating mode. This approach has a drawback

when a number of remote units recorded in the database experience frequent power outages.

15   In such a situation, recording, managing and synchronizing power outage information in the

database is particularly cumbersome when the database is large, perhaps holding status

information for 3 to 4 thousand remote units. This drawback is further compounded when the

database is duplicated multiple times throughout the system. When several thousand

subscribers experience a power outage and AC power is restored before the database has

20   completed recording the power outage, a database approach becomes unwieldy. Another

complicated situation is when multiple remote units lose power at the same time. The affected

remote units cannot all access the channel simultaneously for communicating their status to the

database. A collision avoidance scheme must be implemented that spans a period of time and

that is open for the possibility of power being restored before the database has been completely

revised.

5   This approach has another drawback in that a remote unit entering the sleep

mode consumes system bandwidth in notifying the database. Figure 4 shows an exemplary

flow of internal messaging that occurs between various layers of a remote unit when loss of

AC power is detected and a database is notified of the operational status change. Time is

shown along the vertical axes of Figure 4, with advancing time being indicated toward the

10   bottom of Figure 4. In Figure 4, four layers of the remote unit operating system are shown:

Health; OAM&P (Operations, Administration, Maintenance & Provisioning), MAC (Media

Access Control) and physical. Only MAC layer of the base station is shown. At 40, AC

power failure is detected by the Health layer. At 41, an EVENT message is sent from the

Health layer to the OAM&P layer indicating that AC power has failed. The OAM&P layer

15   sends an ACTION message to the MAC layer at 42. The MAC layer responds at 43 by

sending an ACTION_RSP message to the OAM&P layer indicating that base station

notification is pending. At 44, the MAC layer waits a random length period of time before

sending an unsolicited CAC message at 45 to the MAC layer of the base station indicating the

need for the remote unit to enter the sleep mode. At 46, the MAC layer of the base station

20   sends an acknowledgment message to the MAC layer of the remote unit acknowledging receipt

of the unsolicited CAC message. In response, the MAC layer of the remote unit sends an

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EVENT message at 47 to the OAM&P layer that the notification is done. The OAM&P layer

first sends an EVENT message to the MAC layer indicating that the sleep mode has been

entered at 48, and then sends a message at 49 to the physical layer to power down.

What is needed is a way for a PWAN system to be aware that a remote unit is

5   operating in a sleep mode so that appropriate actions can be taken by the system so that calls

can be completed to a remote unit operating in a sleep mode.

SUMMARY OF THE INVENTION

The present invention provides a method for reducing power consumption of a

10   remote unit in a PWAN system. A remote unit is powered using a battery backup power

supply when an AC power supply fails at the remote unit. A sleep mode of operation is

entered at the remote unit that has a reduced power consumption for the battery backup power

supply. The remote unit is synchronized to a TDD timing structure a predetermined period of

time after entering the sleep mode of operation. A standby mode of operation is then entered

15   at the remote unit in which a CONNECT message indicating an incoming call for the remote

unit is scanned for by the receiver. When no CONNECT message is received, the remote unit

reenters the sleep mode of operation. According to the invention, the predetermined period of

time is a predetermined number of subframes after a boundary subframe of the TDD timing

structure. Preferably, the predetermined number of subframes is based on an identification

20   number of the remote unit.

The present invention also provides a remote unit for a personal wireless area

network that includes a receiver, an AC power supply, a battery-backup power supply and a

controller. The battery-backup becomes operative when the AC power supply fails and

supplies power to the receiver. The controller detects when the AC power supply fails and

controls the receiver and the battery-backup power supply by invoking a sleep mode of

5   operation. The sleep mode of operation is periodically interrupted by the controller controlling

the receiver and the battery-backup power supply to enter a standby mode of operation in

which the receiver scans a CONNECT message indicating an incoming call. The controller

coordinates the sleep mode and the standby mode of operations based on a frame count that is

generated from an identification number of the remote unit.

10   In accordance with another aspect of the invention, a highly bandwidth-efficient

communications method is disclosed for the base station to enable it to communicate with a

remote unit that is in the sleep mode. The remote unit has a unique identification value that is

different from the identification value of other remote units that may be communicating with

the base station. The base station begins by establishing a periodic reference instant at the base

15   station and at the remote station. Then the base station determines a delay interval following

the periodic reference instant at the base station, the delay interval being derived from the

unique identification value of the remote unit. The base station receives spread signals from

the remote units with which it communicates, each comprising an incoming data traffic signal

spread over a plurality of discrete traffic frequencies. The base station adaptively despreads

20   the signals received it receives by using despreading weights. The base station attempts to

initiate a communication with the remote unit that is currently in the sleep mode. If the

attempting step fails to initiate communications with the remote unit, the base station concludes

that the remote unit is in the sleep mode. In response to this, the base station waits for the

delay interval following the periodic reference instant at the base station before transmitting to

the remote unit. The base station then transmits to the remote unit a spread signal comprising

5 an outgoing data traffic signal spread over a plurality of discrete traffic frequencies. The

remote unit has simultaneously changed from the sleep mode to the standby mode and is able

to receive and respond to the spread signal transmitted from the base station.

In accordance additional aspects of the invention, the base station is part of a wireless

discrete multitone spread spectrum communications system. Further, the periodic reference

10 instant is established by a beginning subframe count instant that is incremented by a packet

count value at the base station and at the remote unit. In addition, the delay interval is

determined by a value N of a quantity of M least significant bits of the unique identification

value of the remote unit, the delay interval being an interval required for the occurrence of a

plurality of N of the beginning subframe count instants. The resulting invention enables the

15 base station to be aware that a remote unit is operating in a sleep mode so that appropriate

actions can be taken by the base station to assure that calls can be completed to the remote unit.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the

20 accompanying figures in which like reference numerals indicate similar elements and in which:

Figure 1 is an architectural diagram of the PWAN system, including remote

stations transmitting to a base station;

Figure 2 is an architectural diagram of the remote station X as a sender;

Figure 3 is an architectural diagram of the remote station X as a receiver;

Figure 4 shows an exemplary messaging flow occurring between various layers

of an exemplary remote unit and through an airlink to a base station when a loss of AC power

at the remote unit is detected;

Figure 5 shows a message flow sequence for a terminating call for the situation

when a target remote unit is operating in the sleep mode;

Figure 6 shows a sequence of events with respect 6 ms subframe structure of the

present invention;

Figure 7 is an exemplary graph showing Battery Operating Time, measured in

hours, for Sleep Mode Duty Cycle (:1); and

Figure 8 is an architectural diagram of the base station Z.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 shows an architectural diagram of the personal wireless access network

(PWAN) system described in the referenced Alamouti, Stolarz, et al. patent applications and

which is the environment of the present invention. Two users, Alice and Bob, are located at a

remote station unit, or remote unit (RU), X and wish to transmit their respective data messages

to a base station Z. Remote unit X is positioned to be equidistant from each of antenna

elements A, B, C, and D at base station Z. Two other users, Chuck and Dave, are located at a

remote station unit Y and also wish to transmit their respective data messages to base station Z.

Remote unit Y is geographically different from remote unit X and is not equidistant from each

of antenna elements A, B, C, and D of base station Z. Remote units X and Y, and base station

Z use a form of the CDMA protocol known as discrete multitone spread spectrum (DMT-SS)

5   which is used for providing efficient communications between base stations and remote units.

The DMT-SS protocol is indicated in Figure 1 as a multi-tone CDMA.

In the DMT-SS protocol, a user data signal is modulated by a set of weighted

discrete frequencies or tones. The weights are spreading weights that distribute the data signal

over many discrete tones covering a broad range of frequencies. The weights are complex

10   numbers having a real component that is used for modulating the amplitude of a tone and a

complex component that is used for modulating the phase of the same tone. Each tone in the

weighted-tone set bears the same data signal. Plural users at a transmitting station can use the

same tone set for transmitting their data, but each of the users sharing the tone set has a

different set of spreading weights. The weighted-tone set for a particular user is transmitted to

15   the receiving station where it is processed with despreading weights that are related to the

user's spreading weights for recovering the user's data signal. For each of a plurality of

spatially separated antennas at the receiver, the received multitone signals are transformed

from time-domain signals to frequency-domain signals. Despreading weights are assigned to

each frequency component of the signals that are received by each antenna element. The

20   values of the despreading weights are combined with the received signals for obtaining an

optimized approximation of individual transmitted signals characterized by a particular

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multitone set and transmitting location.

The PWAN system has a total of 2560 discrete tones (carriers) that are equally

spaced in 8 MHZ of available bandwidth in the frequency range of 1850 to 1990 MHZ, with a

spacing between the tones of 3.125 KHz. The tones are used for carrying traffic messages and

5   overhead messages between the base station and the plurality of remote units. The total set of

tones are numbered consecutively from 0 to 2559, starting from the lowest frequency tone.

The tones used for traffic messages are divided into 32 traffic partitions, with each traffic

channel requiring at least one traffic partition of 72 tones.

The overhead message tones are used for establishing synchronization and for

10   passing control information between base stations and remote units. A Common Link Channel

(CLC) is used by a base station for transmitting control information to remote units. A

Common Access Channel (CAC) is used by a remote unit for transmitting messages to the base

station. There is one grouping of tones assigned to each channel. The overhead channels are

used in common by all remote units when control messages are exchanged with a base station.

15   Transmission from a base station to a remote unit is called "forward

transmission" and transmission from a remote unit to a base station is called "reverse

transmission". Time Division Duplexing (TDD) is used by base stations and remote units for

transmitting data and control information in both directions over the same multi-tone frequency

channel. The time between recurrent transmissions in either direction is called a TDD period

20   which, is equal to 3 ms. For every TDD period, there are four consecutive transmission bursts

in each direction. Data is transmitted during each burst using multiple tones. The base station

and each remote unit synchronize and conform to a TDD timing structure and framing

structure that has 1 frame equal to 8 subframes and 1 subframe equal to 2 TDD periods. A

superframe is 256 subframes, or 1536 ms. All remote units and base stations are synchronized

such that all remote units transmit simultaneously and then all base stations transmit

5   simultaneously. When a remote unit initially powers up, it acquires synchronization from a

base station so that control and traffic messages can be exchanged within the prescribed TDD

time format. A remote unit must also acquire frequency and phase synchronization for the

DMT-SS signals so that the remote unit is operating at the same frequency and phase as an

associated base station.

10   Selected tones within each tone set are designated as pilot tones that are

distributed throughout the frequency band and carry known data patterns for enabling an

accurate channel estimation. A series of pilot tones, having known amplitudes and phases, are

spaced apart in frequency by approximately 30 KHz for providing an accurate representation of

a channel response over the entire transmission band, that is, the amplitude and phase

15   distortion introduced by the communication channel characteristics over the transmission band.

FIGURE 2 shows an architectural diagram of remote station X operating as a

sender station. Alice and Bob each input data to remote station X. The data is sent to a vector

formation buffer 202 and also to a cyclic redundancy code generator 204. Data vectors are

output from buffer 202 to a trellis encoder 206. The data vectors are in the form of a data

20   message formed by concatenating a 64K-bit data block with a serially assigned block number.

CRC generator 204 generates LCC vectors that are output to trellis encoder 206. The LCC

vectors are in the form of an error detection message formed by concatenating a CRC value with the serially assigned block number of the data block. The trellis encoded data vectors and LCC vectors are then output to a spectral spreading processor 208. The resultant data tones and LCC tones are then output from processor 208 to a transmitter 210 for transmission to the

5   base station.

The personal wireless access network (PWAN) system described in the cross-referenced Alamouti, Stolarz, et al. patent application provides a more detailed description of a high-capacity mode, where one traffic partition is used in one traffic channel. A base station transmits information to multiple remote units that are located in the base station's cell. The

10   transmission formats are for a 64 Kbps traffic channel, together with a 4 Kbps Link Control Channel (LCC) between the base station and a remote unit. A binary source, for example, Alice or Bob, delivers data, or information bits, to a sender transmitter at 64 Kbits/sec. This translates to 48 bits in one transmission burst. The information bits are encrypted according to a triple data encryption standard (DES) algorithm. The encrypted bits are then randomized in

15   a data randomization block. A bit-to-octal conversion block converts the randomized binary sequence into a sequence of 3-bit symbols. The symbol sequence is converted into 16 symbol vectors. The term vector generally refers to a column vector, which is generally complex. One symbol from the LCC is added to form a vector of 17 symbols.

The 17-symbol vector is trellis encoded starting with the most significant

20   symbol (first element of the vector) and is continued sequentially until the last element of the vector (the LCC symbol). This process employs convolutional encoding for converting the

input symbol (an integer between 0 and 7) to another symbol (between 0 and 15) and maps the

encoded symbol to its corresponding 16 QAM (or 16 PSK) signal constellation point. The

output of the trellis encoder is therefore a vector of 17 elements where each element is a signal

within a set of 16 QAM (or 16 PSK) constellation signals. (The term signal will generally

5   refer to a signal constellation point.)

A link maintenance pilot signal (LMP) is added to form an 18-signal vector,

with the LMP as the first element of the vector. The resulting (18 x 1) vector is pre-multiplied

by a (18 x 18) forward smearing matrix yielding an (18 x 1) vector b. Vector b is element-

wise multiplied by an (18 x 1) gain preemphasis vector yielding another (18 x 1) vector c.

10   Vector c is post-multiplied by a (1 x 32) forward spatial and spectral spreading vector yielding

a (18 x 32) matrix R(p), where p denotes the traffic channel index and is an integer. The 32

columns of matrix R results from multiplying the spectral spreading factor 4 and spatial

spreading factor 8. The (18 x 32) matrices corresponding to all traffic channels carried (on the

same traffic partition) are then combined (added) for producing a resulting 18 x 32 matrix S.

15   Matrix S is partitioned by groups of four columns into eight (18 x 4)

submatrices A_0 to A_7. The indices 0 to 7 of submatrices A_0 to A_7 correspond to the antenna

elements over which these symbols will eventually be transmitted. Each submatrix is mapped

to tones within one traffic partition. A lower physical layer places the baseband signals in

discrete Fourier transfer (DFT) frequency bins where the data is converted into the time-

20   domain and sent to its corresponding antenna elements (0 to 7) for transmission. This process

is repeated from the start for the next 48 bits of binary data to be transmitted in the next

forward transmission burst.

Figure 3 is an architectural block diagram of remote station X operating as a

receiving station. Data tones and LCC tones are received by remote station antenna X and a

receiver 610. Receiver 610 passes the data tones and the LCC tones to a spectral despreading

5   processor 612 which despreads the data tones and LCC tones. The despread signals are then

output from processor 612 to a trellis decoder 614. Trellis decoder 614 generates data vectors

from the despread signals. The data vectors are then output to a vector disassembly buffer

616. Data for Alice and data to Bob are output from buffer 616 to Alice and Bob,

respectively. Data for Alice and Bob are also input to a CRC generator 618. CRC generator

10   618 computes a new CRC value for every 64 K-bit data block and outputs the new CRC value

with the block number to a buffer within a CRC comparison processor 620. The receiving

station buffers error detection messages that are received from the link control channel in CRC

comparison processor 620 so that the error detection messages are accessible by their block

numbers N, N+1, N+2, etc. When the receiving station receives a data message on the

15   traffic channel, it performs a CRC calculation on the data block in the message with CRC

generator 618 for obtaining a resulting new CRC value. If the comparison determines that

there is a difference in the values, then an error signal is generated by an error signal generator

622. The error signal can be processed and used in several ways by an error processor 630.

For example, the error signal can initiate a negative acknowledgment signal that is to be sent

20   from the receiving station back to the sender station requesting that the sender repeat

transmission of the data block. The error signal can also initiate an update in spreading and

despreading weights at the receiving station for improving the signal-to-interference and noise

ratio of the traffic channel. Another use of the error signal is for initiating an alarm used for

other real time control. Yet another use of the error signal is as part of a logging signal for

compilation of a long term report relating to traffic channel quality.

5   According to the invention, a remote unit includes a standby mode of operation

and a sleep mode of operation. Normally, the standby mode is the mode in which a remote

unit scans the CLC channel for a CONNECT message for the remote unit. The sleep mode of

operation provides a reduced power consumption operating mode for extending remote unit

battery runtime during an AC power outage condition. During the sleep mode of operation,

10   the remote unit periodically switches between the standby mode and sleep mode, with the

overall effect being a reduction in the average power required by the remote unit.

          Delivery of a CONNECT message to a remote unit operating in the sleep mode

is scheduled so that the remote unit is in the standby portion of the sleep mode. That is, the

remote unit is synchronized and ready for receiving data from the CLC when the base station

15   begins transmitting on the CLC. In order to achieve synchronization, a system wide Packet

Count (PKT_CNT) is used. The basic unit of measure for synchronization is a mod[8]

PKT_CNT, which is called a subframe count (SUBFRM_CNT). The SUBFRM_CNT is

incremented every 256 PKT_CNTs, or every 6 ms.

          The base station and the remote unit both preferably use the least significant 8

20   bits of the remote unit ID for determining the particular SUBFRM_CNT at which the CLC

CONNECT message should be sent to the remote unit and, simultaneously, the appropriate

time at which the remote unit should be in the standby portion of the sleep mode for receiving

the CONNECT message. When the least significant 8 bits of the remote unit ID are used, the

remote unit enters the standby mode once every 256 subframes and is ready for receiving an

incoming call. The particular subframe that a remote unit will be ready for receiving an

5   incoming call is called the N_{listen} for the remote unit.

To avoid using a remote unit power status database that is maintained at a

central location, the sleep mode features of the present invention are preferably implemented as

part of a standard terminating call retry mechanism. That is, when a terminating call request is

received at the base station MAC Layer, the MAC Layer Access Manager proceeds normally

10   through a terminating call setup procedure by transmitting a CONNECT message on the CLC

to the target remote unit. In the situation when the target remote unit is operating in the sleep

mode at the time of the CONNECT message transmission, the remote unit will generally be

unable to process the message. The base station MAC Layer Access Manager will time-out

and retry transmission of the CONNECT message. Preferably, a retry timer T_r is nominally

15   set to 72 ms. The base station MAC Layer Access Manager retries the CONNECT message

for a predetermined number of tries that is set by a system manager. Preferably, the retry

count is 2.

When the number of retries equals the retry count, the base station MAC Layer

Access Manager determines that the remote unit is in the sleep mode and, consequently,

20   attempts to deliver the CONNECT message at a scheduled time that is based on the target

remote unit ID. The scheduled time is a subframe occurring N_{listen} subframes after the

boundary subframe for the TDD timing structure.

The base station MAC Layer Access Manager also reserves the CLC slot(s) required for completing the CLC CONNECT message transmission at the time the N_{listen} subframe number is derived. That is, when the base station MAC Layer Access Manager has reached its retry count for a CONNECT message and has determined the N_{listen} subframe, CLC slot availability is examined for reserving the appropriate CLC slot(s) for use. As an alternative, a remote unit can scan up to 3 CLC slots for a CONNECT message when in the sleep mode so that a base station can select from 3 CLC slots in case a specific slot is unavailable.

Figure 5 shows a message flow sequence for a terminating call for the situation when a target remote unit is operating in the sleep mode. The MAC Layer of the base station receives a terminating call request at 50. At 51, the MAC Layer of the base station sends a CLC CONNECT message to the target remote unit. Since the remote unit is in the sleep mode, it does not receive the CLC CONNECT message and, therefore, does not respond. Since there is no response from the target remote unit during the T_{retry} period 52, the MAC Layer of the base station sends a second CLC CONNECT message to the target remote unit at 53. The remote unit does not respond during T_{retry} 54, so the MAC Layer of the base station determines the N_{listen} subframe for the remote unit using the least significant 8 bits of the remote unit ID and waits for the particular N_{listen} subframe at 55. At N_{listen} for the remote unit, the MAC Layer of the base station sends a CLC CONNECT message at 56. At N_{listen}, the remote unit is in the standby mode and ready to receive the CLC CONNECT message at 57.

In response, the remote unit MAC Layer sends a CAC_ACK message to the base station at 58.

The following definitions are used for describing the sleep mode of operation of

the present invention:

T_{sleep} = the time that a remote unit is in a low-power mode (i.e., sleeping).

5 T_{sync} = the time required by a remote unit for re-acquiring synchronization when

exiting the sleep mode.

T_{scan_clc} = the time that a remote unit is operating in a standby mode scanning the

CLC for a CONNECT message.

$T_{standby}$ = the total time a remote unit is running (i.e., $T_{sync} + T_{scan\_clc}$)

10 D_{sleep} = $T_{sleep} + T_{standby})/T_{standby}$, that is, the definition of the duty cycle of the

sleep mode duty cycle.

Since the base station transmits the CONNECT message at the N_{listen} subframe

so that the call can be completed, and the remote unit therefore must be ready for receiving the

messages on the CLC channel at the N_{listen} subframe. The remote unit MAC Layer Access

15 Manager is capable of deriving the N_{start_sync} subframe number and insures that all hardware

required for the remote unit synchronization and CLC scanning efforts are released from sleep

mode at that time. This is done, for example, by using a programmable hardware counter 640

that is clocked in synchronism with the TDD subframe of the system, as shown in Figure 3.

Prior to entering the sleep mode, or at the time the sleep mode is entered, CPU 650 preferably

20 uses the least significant 8 bits of the remote unit ID for determining the N_{listen} subframe for the

remote unit. CPU 650 loads counter 640 with a value related to N_{listen} and synchronizes

counter 640 using a Start Sync signal. Counter 640 provides an interrupt to CPU 650 once

every 256 subframes, initiating a re-synchronization process. CPU 650 responds by

controlling power supply 660 to provide power 661 to the various components of remote unit

used for receiving a CLC CONNECT message. CPU 650 also outputs an enabling signal to

5   the spectral despreading processor 612 to enable the remote unit to receive messages from the

base station.

The remote unit begins its re-synchronization effort at a subframe N_{start_sync} that

occurs some determined period of time prior to the occurrence of the N_{listen} subframe.

Simulations of the remote unit synchronization algorithms indicate that a remote unit acquires

10   synchronization with a base station when exiting a period of sleep in a minimum time of 122

ms and a maximum time of 200 ms. The actual time additionally depends on hardware

component tolerances, the ambient temperature and numerous other factors. For the purposes

of this disclosure, a worst case synchronization acquisition time T_{sync} of 200 ms is used. This

equates to approximately 34 subframes. Therefore, $N_{start\_sync} = N_{listen}$ - 34 subframes.

15   Figure 6 is a timing diagram showing the sequence of events for a remote unit

operating in the sleep mode. Each vertical line in Figure 6 represents a subframe boundary.

The time between each subframe boundary is 6 ms. A remote unit is shown as being in a sleep

mode. At N_{start_sync}, counter 640 sends an interrupt request to CPU 650 (Figure 3). CPU 650

responds by controlling power supply 660 to provide power to the various components of the

20   remote unit needed for receiving a CLC CONNECT message. In Figure 6, the remote unit is

in the sleep mode at 60. At 61, N_{start_sync} occurs and the remote unit resynchronizes for a

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number of subframes. Preferably, about 34 subframes are required for a remote unit to

reacquire synchronization. At N_{listen}, the remote unit scans the CLC channel for any CLC

CONNECT messages for the remote unit. The remote unit scans for 2 subframes, as shown in

Figure 6 at 62. The remote unit can also be set to scan for a CLC CONNECT message over a

5   different number of subframes other than 2 subframes depending upon system requirements. If

no CLC CONNECT message is received at N_{listen}, the remote unit returns to the sleep mode at

63. If a CLC CONNECT message is received, the call is established in a normal manner.

As a first illustrative example of the timing aspects of the sleep mode of the

present invention, the least significant 8 bits of a remote unit ID are used so that the N_{listen}

10   cycle time is 1536 ms (256 x 6 ms). The remote unit synchronization acquisition time N_{sync} is

estimated to be 34 subframes (204 ms), and a CLC scan time for 2 CLC subframes is chosen.

It follows that,

$$T_{sleep} = 220 \text{ subframe times} = 220 \times 6 \text{ ms} = 1.320 \text{ s}$$

$$T_{sync} = 204 \text{ ms} = 34 \text{ subframes} \times 6 \text{ ms}$$

15    $$T_{scan\_clc} = 12 \text{ ms} = 2 \text{ subframes} \times 6 \text{ ms}$$

$$T_{standby} = 212 \text{ ms}$$

Therefore, the total sleep mode/standby mode cycle time is 1536 ms, and the

total remote unit power-on time is 212 ms. The overall duty cycle is 7.25:1. For this

example, the maximum delay for delivery of a CONNECT message is 1.530 seconds (1536 ms

20   - 6 ms). The nominal CONNECT message delay delivery time is about 0.766 seconds.

Using a longer delay in CONNECT message delivery time permits the remote

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unit to be in the sleep mode for a greater period of time. As another example, the N_{listen}

subframe is determined by using the least significant 9-bits of a remote unit ID. Thus, the

N_{listen} interval is 512 subframes. In this example, even though the sleep time is longer, the

maximum synchronization acquisition time T_{sync} remains the same. This is based on the fact

5   that any temperature change of the remote unit is not sufficient for requiring a coarse TDD

synchronization to be performed. It follows that,

$$T_{sleep} = 476 \text{ subframe times} = 476 \times 6 \text{ ms} = 2.856 \text{ s}$$

$$T_{sync} = 204 \text{ ms} = 34 \text{ subframes} \times 6 \text{ ms}$$

$$T_{scan\_clc} = 12 \text{ ms} = 2 \text{ subframes} \times 6 \text{ ms}$$

10    $$T_{standby} = 212 \text{ ms}$$

The total sleep mode/standby mode cycle time is 3072 ms (512 x 6 ms), and the

total remote unit power-on time is 212 ms. The overall duty cycle is 14.5:1. For this

example, the maximum delay of delivery of a CONNECT message is 3.066 seconds (3072 ms

- 6 ms). The nominal time for delivery of a CONNECT message is about 1.536 s.

15   Table I below summarizes various scenarios:

TABLE I

Sleep Time (ms)	Nominal CLC CONNECT message delay time (ms)	RU Synchronization Time (ms)	RU Power Duty Cycle (approx.)	Battery Runtime (approx. hrs)
1320	663	220	7.25:1	11.5
1320	663	150	9:1	12

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2856	1428	150	18:1	13.5
2856	1428	200	14:5	13
2856	1428	300	10:1	12

5   The situation of a call originating from a remote unit that is operating in the

sleep mode is straight forward compared to the situation when a call terminates at a sleeping

remote unit. That is, the remote unit exits the sleep mode in response to a user command.

The originating call delivery time, i.e., the time taken for delivering an ACCESS message on

the CAC, is delayed by approximately 200 ms since the remote unit must re-acquire

10   synchronization before the ACCESS message may be transmitted.

          In normal system operation, a base station polls remote units at a periodic rate

for determining status of each remote unit. Each remote unit responds to the Poll Request

message with a Poll response message using the CAC channel. When a remote unit is in a

sleep mode of operation, the Poll Request message will not be received and, consequently, the

15   remote unit will not respond with a Poll Response message. The present invention provides

two alternatives for handling such a situation from the system point of view. The first

approach is to always schedule a Poll Request message to arrive at a remote unit during the

N_{listen} subframe for the remote unit whether the remote is in the standby or the sleep mode.

The remote unit will receive the Poll Request message regardless of AC power status. A

20   disadvantage associated with this approach is that the CAC channel is used by the remote unit

for a Poll Response message, causing the remote unit transmitter to be used, effectively

wasting battery power when in the sleep mode.

The alternative approach is for a remote unit to ignore the Poll message from the base station during AC power outage situations and allow an OAM&P Layer at the base station to recognize that a non-responsive remote unit may possibly be in the sleep mode and,

5 consequently, be aware of the power status of the remote unit in questions power.

Figure 7 is an exemplary graph showing Battery Operating Time, measured in hours, for Sleep Mode Duty Cycle (:1). From Figure 7, it is apparent that the length of time that a remote unit is sleeping has a significant impact on the run time of the battery. Also, from Figure 7, it is also apparent that the battery run time begins to flatten with duty cycle

10 after about a 10:1 ratio. Lab results for simulated sleep mode operation with a new, 7.2 amp-hour battery installed in a prototype uninterruptable power supply have yielded runtimes between 12 hours, 12 minutes to 12 hours, 32 minutes under the conditions that the remote unit is at room temperature, the sleep mode period is set for 3 seconds, and the sleep mode duty cycle is 10:1 (0.3 s standby state and a 2.7 s sleep state).

15 A remote unit operating in the sleep mode preferably provides the following characteristics:

Sleep time = 2856 ms

RU Synchronization Time = 200 ms

Call delivery delay = 1428 ms nominally

20 RU CLC Scan time = 36 ms (i.e., three slots for flexibility at Base MAC Layer)

Total Cycle Time = 3092 ms

Standby Time = 236 ms

Duty Cycle = 13:1 (approx.)

Battery Operating Time = 12.5 hours (approx.)

5   FIGURE 8 is an architectural diagram of the base station as a sender. The PSTN inputs

data to base station Z. The data is sent to the vector formation buffer 502 and also to the

cyclic redundancy code generator 504. Data vectors are output from buffer 502 to the trellis

encoder 506. The data vectors are in the form of a data message formed by concatenating a 64

K-bit data block with its serially assigned block number. The LCC vectors output from the CRC

10   generator 504 to the trellis encoder 506 are in the form of an error detection message formed by

concatenating the CRC value with the block number. The trellis encoded data vectors and

LCC vectors are then output to the spectral and spatial spreading processor 508. The resultant

data tones and LCC tones are then output from processor 508 to the transmitter 210 for

transmission to the remote station.

15   The base station transmits the CONNECT message at the N_{listen} subframe so that

the call can be completed to the remote unit. The base station knows to send the messages on

the CLC channel at the N_{listen} subframe. The base station's MAC Layer Access Manager is

capable of deriving the N_{start_sync} subframe number. This is done, for example, by using a

programmable hardware counter 540 that is clocked in synchronism with the TDD subframe of

20   the system, as shown in Figure 8. When the base station wants to send a message to the

remote unit, the CPU 550 preferably uses the least significant 8 bits of the remote unit ID for

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determining the N_{listen} subframe for the remote unit. CPU 550 loads counter 540 with a value

related to N_{listen} and synchronizes counter 540 using a Start Sync signal. Counter 540 provides

an interrupt to CPU 550 once every 256 subframes, initiating a re-synchronization process.

CPU 550 responds by outputting an enabling signal to the spectral and spatial spreading

5   processor 508 to enable the base station to transmit messages to the remote unit when the

remote unit is in its standby mode.

Still another alternate embodiment applies the above described invention in the PWAN

Frequency Division Duplex Communications System described in the Alamouti, Michaelson et

al. patent application cited above.

10   Although the preferred embodiments of the invention have been described in detail

above, it will be apparent to those of ordinary skill in the art that obvious modifications may be

made to the invention without departing from its spirit or essence. Consequently, the

preceding description should be taken as illustrative and not restrictive, and the scope of the

invention should be determined in view of the following claims.

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